HOLOCENE BIOGEOGRAPHY OF SPRUCE–FIR FORESTS IN SOUTHEASTERN ARIZONA—IMPLICATIONS FOR THE ENDANGERED MT. GRAHAM RED SQUIRREL

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Abstract

Pollen, plant macrofossils, and radiocarbon dates on sediments from a small cienega on Mt. Graham in southeastern Arizona suggest that the occurrence of the present Engelmann spruce–subalpine fir forest on the mountaintop extends back to at least 8000 years ago. This is important biogeographically, since the forest type reaches its southernmost limit on Mt. Graham, and ecologically, as it is the primary habitat of the endangered Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*).

Studies of Holocene biogeography and vegetation change in southern Arizona and New Mexico have been largely limited to the study of packrat (*Neotoma*) middens (see compilation in Van Devender 1990a, b), or from cores of sediment deposited in playa lakes such as Willcox Playa (Martin 1963; Martin and Mehringer 1965), Lake Estancia (Bachhuber and McClellan 1977) or the San Agustin Plains (Clisby and Sears 1956; Markgraf et al. 1984). Midden and playa lake records have been most useful for vegetation reconstructions at low- to mid-elevations within the region. In contrast, the Holocene vegetation history of higher elevation forest types, such as the modern Engelmann spruce (*Picea engelmannii*)–subalpine fir (*Abies lasiocarpa*) association, presently confined to elevations above ca. 2700 m on isolated mountain ranges within the region (Moir and Ludwig 1979), is largely unknown. Characteristics of this vegetation type are not recorded by analysis of either playa or packrat midden deposits.

However, cienegas, small sedimentary basins occurring on several of the higher mountains within the region, serve as sites for the accumulation of plant materials through time. To better understand the vegetation history of the spruce–fir forest type, sediment cores were obtained from the High Water (Emerald Springs) Cienega on Mt. Graham in the Pinaleño (or Graham) Mountains, Graham

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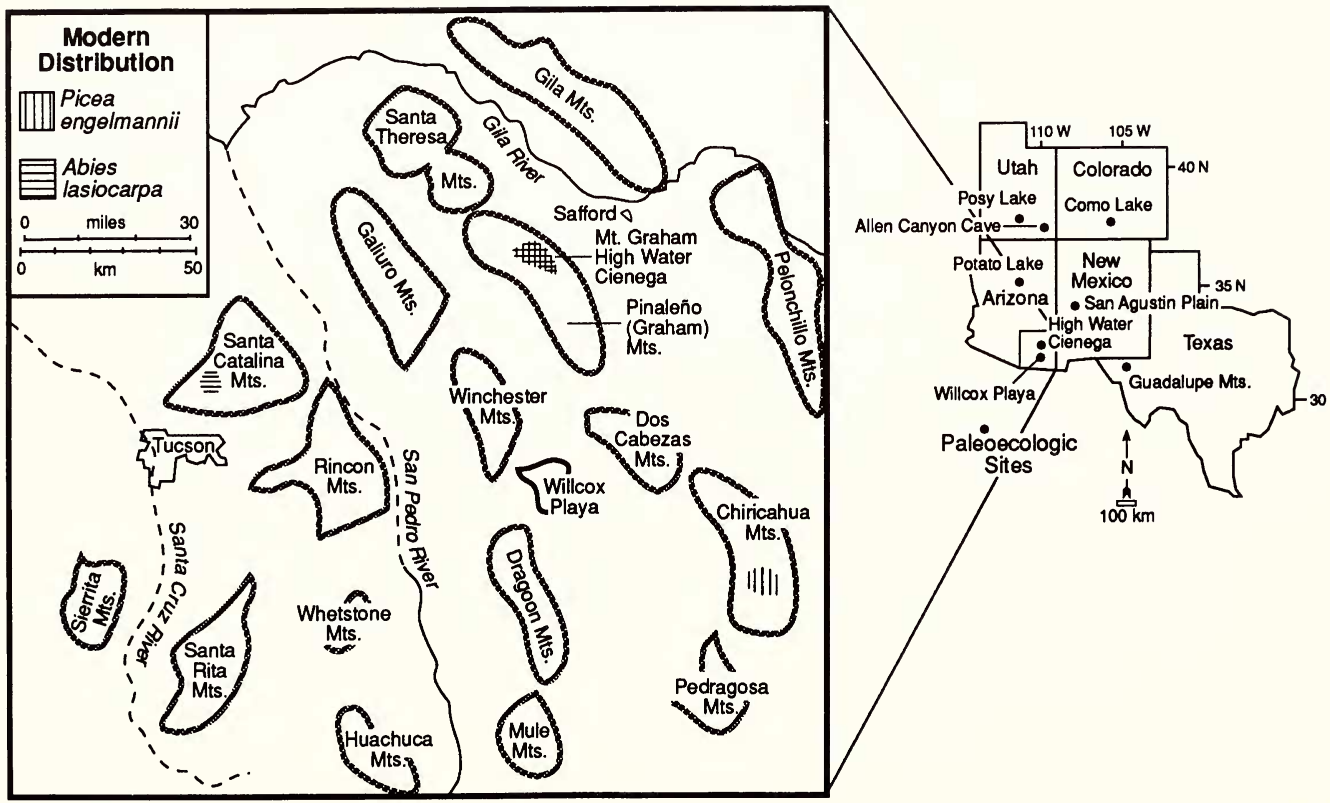

FIG. 1. Location of High Water (Emerald Springs) Cienega, Mt. Graham, Pinaleno Mountains, Arizona, in relation to other sites mentioned in the text.

County, Arizona (Fig. 1). The cienega, in actuality a wet meadow, is located in a small nivation hollow at 3143 m (32°42′00″N, 109°53′30″W; Webb Peak 7.5′ USGS Quadrangle). The site is ca. 20 km southwest of Safford and 120 km northeast of Tucson, Arizona.

A study of the Engelmann spruce–subalpine fir vegetation type through time in southeastern Arizona is important in understanding the factors determining its southern range limit, which occurs in the Pinaleño Mountains (Pase and Brown 1982). The old growth Engelmann spruce–subalpine fir forest type is the preferred habitat of the endemic, endangered Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) (Brown 1984), found today only on Mt. Graham, the highest peak in the range.

Vegetation surrounding the cienega today consists predominantly of Engelmann spruce with a few individuals of subalpine fir. Understory growth is sparse, consisting of currant (*Ribes wolfii*), orange gooseberry (*R. pinetorum*), cranesbill (*Geranium richardsonii*) and blueberry (*Vaccinium myrtillus*) (nomenclature follows Johnson 1988). Grasses (Poaceae) and sedges (Cyperaceae) cover the cienega proper. At the lower border of the subalpine forest (ca. 2920 m), Engelmann spruce and subalpine fir mix with Douglas-fir (*Pseudotsuga menziesii*), southwestern white pine (*Pinus strobiformis*), ponderosa pine (*P. ponderosa*), quaking aspen (*Populus tremuloides*) and willow (*Salix scouleriana*) (Whittaker and Niering 1965). A complete list of plants occurring in the range is found in Johnson (1988).

Methods

A 134-cm core (#1) was extracted with a modified Dachnowsky corer outfitted with a 50-cm core barrel on 5 October 1986. An additional 119-cm core (#2) was obtained on 15 October 1987. Sediment is mostly sandy peat or peaty sand, with sand increasing toward the base. Sparse oxidized granitic granules occur below 100 cm depth.

Pollen was concentrated from the raw sediment of core #1 by standard chemical techniques (Faegri and Iversen 1975), including treatments with dilute KOH, HCl, HF, and acetolysis solution, with final suspension in silicone oil. *Lycopodium* tracer spores were added for calculation of pollen concentration. Because of poor pollen recovery from core #1, the procedure was slightly modified for core #2, eliminating the KOH treatment and limiting the time for acetolysis digestion to 30 seconds. For plant macrofossil and charcoal analysis, five-cm long, half-core sections of core were allowed to disaggregate overnight in water, and the macrofossils were extracted by gentle water washing of the sediment over U.S. Standard Soil

TABLE 1. RADIOCARBON DATES FOR THE HIGH WATER (EMERALD SPRINGS) CIENEGA SEDIMENT CORES, PINALEÑO MOUNTAINS, ARIZONA.

Laboratory #	Core	Depth (cm)	Date (yr BP)
Beta-18365	1	121–129	8250 ± 160
Beta-32263	2	107–112	6010 ± 150

Sieves (mesh 20 and 80). The laboratory analyses were performed both at the Palynology Laboratory, Department of Geosciences, University of Arizona, and at the Laboratory of Paleoecology, Bilby Research Center, Northern Arizona University.

RESULTS

Basal radiocarbon dates (core #1, 8250 ± 160 yr BP; core #2, 6010 ± 150 yr BP) suggest the record from High Water Cienega extends back into the early middle Holocene (Table 1). Pollen assemblages were analyzed from 13 samples of core #1. A minimum of 29 pollen and spore types were found in these samples. Pollen preservation was excellent and pollen concentration was high (to 130,000 grains cc^{-1} of raw sediment) for the top 10 cm of the core, but declined rapidly with depth (Table 2). This was true for individual major pollen types encountered in the analyses including spruce (*Picea*), fir (*Abies*), pine (*Pinus*), oak (*Quercus*), composite and goosefoot families (Compositae and Chenopodiaceae, respectively). The exception to this was pollen of the grass family (Gramineae) that remained relatively abundant throughout the core (median value = 16,000 grains cc^{-1}). Pollen concentration declined with depth, probably reflecting decreased preservation. Pollen recovery from core #2 was similar to core #1.

Identifiable plant macrofossil remains were also recovered from both cores. Charcoal particles were very abundant within the stratigraphic column. The dominant identifiable macroremains were Engelmann spruce needle fragments, found in the three levels analyzed in core #1, and at 11 of the 12 levels analyzed for core #2. Needle fragments of subalpine fir as well as achenes of sedge (*Carex*) were also found, although at fewer levels (Table 3). All fragments were carbonized and their preservation was probably enhanced due to burning during ancient forest fires.

DISCUSSION

The co-occurrence of Englemann spruce with subalpine fir remains in fossil deposits of late Wisconsin age is rare; subalpine fir has only been recorded from Allen Canyon Cave, Utah (Betancourt 1984, 1990). However, Engelmann spruce has been identified from several

TABLE 2. POLLEN CONCENTRATION (GRAINS/CC) FOR SELECTED POLLEN TYPES, CORE #1, HIGH WATER (EMERALD SPRINGS) CIENEGA, PINALEÑO MOUNTAINS, ARIZONA.

Depth (cm	Estimated Age (yr BP)	*Picea*	*Abies*	*Pinus*	*Quercus*	Other Compositae	Cheno-*Ams*	Gramineae	Total
0	0	69210	2375	11535	1360	5770	6785	24430	133,000
10	660	9630	4740	2220	590	2075	4300	19705	49,500
25	1650	13615	0	1300	0	2600	4540	14910	45,375
30	1980	2240	450	900	300	2540	3000	31520	48,250
40	2640	4070	0	510	0	4070	7120	26440	33,250
50	3300	1860	0	2320	1395	1625	2670	10090	30,850
60	3960	1400	0	280	560	1120	1955	10330	20,400
75	4950	1325	95	380	0	95	1140	33415	38,200
80	5280	500	0	500	0	0	500	8430	7150
95	6270	4565	210	1450	1040	1450	4770	165735	191,250
105	6930	500	0	0	750	1490	250	15910	20,200
110	7260	1630	0	130	485	840	575	19030	27,150
120	7920	0	0	0	430	1720	860	13750	17,850

TABLE 3. MACROFOSSILS EXTRACTED FROM CORE #2, HIGH WATER (EMERALD SPRINGS) CIENEGA, PINALEÑO MOUNTAINS, ARIZONA.

Depth (cm)	Estimated Age (yr BP)	*Picea engelmannii*	*Abies lasiocarpa*	Macro-charcoal	*Carex*
0–5	0–274	N, O, S, T	N, S	X	Nt
7.5–12.5	412–686	N, T		X	Nt
17.5–22.5	960–1235			X	Nt
27.5–32.5	1510–1784	N		X	
37.5–42.5	2058–2333	N		X	
47.5–52.5	2608–2882	N		X	
57.5–62.5	3156–3430	N		X	
67.5–72.5	3705–3980	N		X	
77.5–82.5	4254–4528	N	N	X	
87.5–92.5	4803–5077	N		X	
97.5–102.5	5351–5626	N		X	
110.5–115	6037–6312	N		X	

N = needle fragment; Nt = nutlet; O = other; S = seed or seed wing; T = twig; X = charcoal present.

locations below its modern elevational limit during the late Wisconsin, including Allen Canyon Cave, Utah (2200 m; Betancourt 1984), Potato Lake, Arizona (2222 m; Anderson 1989) and the Guadalupe Mountains, Texas (2000 m; Van Devender et al. 1979). Spruce pollen (Clisby and Sears 1956) as well as spruce needles (Markgraf et al. 1984; no specific identification) were found in sediments of San Agustin Lake, New Mexico (2065 m), dating ca. 15–18,000 years ago. Spruce pollen was also recovered from Pluvial Lake Cochise sediments at 1260 m elevation near Willcox, Arizona (Martin 1963; Martin and Mehringer 1965). Occurrence of spruce at these locations suggests that either Engelmann or blue spruce was more abundant within the drainages of those lakes during the late Wisconsin. Of the two, Engelmann spruce is the most likely; today the tree grows as low as 2800 m in the Chiricahua Mountains (Moir and Ludwig 1979) and 2700 m in the Pinaleños (Whittaker and Niering 1965). This represents a minimum lowering of 700 m elevation during the late Wisconsin.

Climatic conditions causing elevational depressions of 700 m may have been insufficient to establish a corridor allowing subalpine species to span gaps between mountain ranges of the region. Based upon fossil pollen evidence, Jacobs (1985) suggested Wisconsin-age spruce occurrence in the White Mountains of Arizona, the closest known locality to Mt. Graham. From the White Mountains, spruce could have expanded southwest into the Gila Mountains. Even so, spanning the Gila River valley, with a floor of ca. 800–1050 m, would have been unlikely. Similarly, spruce potentially could have grown in the Santa Teresa and Pinal mountains to the northwest of the Pinaleños. However, significant gaps of low elevation would have impeded movement between those ranges and Mt. Graham also. To the southwest, gaps of 20–30 km would have existed between the Dos Cabezas and Chiricahua mountain ranges. Although spruce is absent from them today, several other ranges to the southwest of Mt. Graham (Santa Catalina, Huachucha and Santa Rita) could have had viable populations of spruce during the Pleistocene, but are even further away from those discussed above.

These data suggest that the subalpine forest on Mt. Graham has been isolated from other populations since a glacial episode prior to the late Wisconsin. If true, isolation of the Mt. Graham red squirrel may have paralleled that of spruce there. Location and analysis of packrat middens from elevations within the potential Pleistocene range of spruce should provide answers to the late Wisconsin distribution of the subalpine forest.

By the early Holocene, however, Engelmann spruce, retreating upslope in response to warmer summer temperatures, had became established within its modern elevational range in southern Colorado (by ca. 10,500 yr BP at Como Lake, 3523 m; Shafer 1989; Jodry et al. 1989), southern Utah (by ca. 9000 yr BP at Posy Lake, 2653 m; Shafer 1989) and in southern Arizona at High Water Cienega. With the High Water Cienega data it cannot be determined when spruce was established on Mt. Graham, but it was present by at least 8000 years ago. The occurrence of spruce at high elevations in southern Arizona by this time coincides with the demise of the lowland juniper woodlands and the change from a single season (winter) to a biseasonal (winter and summer) precipitation regime, as discussed by Van Devender (1990a, b) and earlier publications.

Deposits containing identifiable organic remains are very rare at the highest elevations of mountain ranges within the desert regions of southern Arizona and New Mexico. This is probably due to a lack of suitable deposition sites in ranges that did not experience Pleistocene glaciation, such as the Pinaleño Mountains. Small Wisconsin-age nivation hollows, such as those on Mt. Graham, hold the potential for accumulation of organic remains during the Holocene. However, problems in preservation of pollen and plant macrofossils may exist. Even though limited, the records from High Water Cienega provide initial information on the antiquity of the spruce–fir forest at high elevations within the region.

Conclusions

Three tentative conclusions are deduced from these preliminary data. First, High Water Cienega is at least 8250 radiocarbon years old. The lack of clear sediment hiatuses suggests this rare, high-elevation wetland, an important source of moisture for wildlife in the mountain range, has existed over the last 8000 years. Second, remains of Engelmann spruce are found in virtually all macrofossil samples analyzed so far from the Mt. Graham cores, suggesting it has persisted continuously near the site for at least the last 8000 years, and provides a minimum age for the establishment of the forest type. Although the record for subalpine fir is less definitive, the trace amounts of *Abies* pollen at nearly all sediment levels (Fig. 1) suggests fir was probably present around the cienega. Consequently, what is today the preferred habitat of the Mt. Graham red squirrel has been present at the site for at least 8000 years. In addition, the forests of Mt. Graham probably have been isolated since before the last glaciation. Third, since macroscopic charcoal is abundant in all core samples and virtually all recovered macrofossils are carbonized, fires have regularly burned the cienega and surrounding upland areas during the Holocene. Additional analyses are needed from similar locations within the desert southwest to provide a more specific picture of vegetation changes at high elevations during the Holocene.

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